Electronic Version
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Claims

[c1] What is claimed is:

1. A bandgap reference circuit comprising:

a first bandgap reference unit having an output connected to a first node (n1);

a second bandgap reference unit having an output connected to a second node (n2); and

a subtractor comprising:

a first transistor (M4) having a source connected to a first voltage, and a drain and a gate both connected to the second node (n2);

a second transistor (M5) having a source connected to the first voltage, a drain connected to a third node (n3), and a gate connected to the gate of the first transistor (M4);

a third transistor (M6) having a source connected to a second voltage, and a drain and a gate both connected to the first node (n1);

a fourth transistor (M7) having a source connected to the second voltage, a drain connected to the third node (n3), and a gate connected to the gate of the third transistor (M6); and

an output resistor (RREF) connected between the third

node (n3) and the second voltage.

[c2] 2. The bandgap reference circuit of claim 1 wherein the first and second transistors (M4, M5) are PNP, the third and fourth transistors (M6, M7) are NPN, the second voltage is ground, and the first voltage is substantially higher than ground.

[c3] 3. The bandgap reference circuit of claim 2 wherein the first bandgap reference unit is a CMOS p-channel bandgap reference, and the second bandgap reference unit is a CMOS n-channel bandgap reference.

[c4] 4. The bandgap reference circuit of claim 3 wherein the first and second bandgap reference units produce output reference voltages of under 1 volt at the first and second nodes (n1, n2) respectively.

[c5] 5. The bandgap reference circuit of claim 1 wherein the first voltage is approximately 0.9 volts relative to the second voltage being ground such that an output reference voltage at the third node (n3) is between 550 and 570 millivolts.

[c6] 6. The bandgap reference circuit of claim 1 wherein the first bandgap reference unit comprises:
a first operational amplifier (112) having positive and negative input ends and an output end;

a fifth transistor (M1) having a source connected to the first voltage, a drain connected to the positive input end, and a gate connected to the output end;
a sixth transistor (M2) having a source connected to the first voltage, a drain connected to the negative input end, and a gate connected to the output end;
a first resistor (R1) connected between the second voltage and the positive input end;
a second resistor (R2) connected between the second voltage and the negative input end;
a first diode (Q1) having a collector and base connected to the second voltage, and an emitter connected to the positive input end through a third resistor (R3);
a second diode (Q2) having a collector and base connected to the second voltage, and an emitter connected to the positive input end; and
a seventh transistor (M3) having a source connected to the first voltage, a gate connected to the output end, and a drain connected to the first node (n1).

[c7] 7. The bandgap reference circuit of claim 6 wherein the second voltage is ground and the first voltage is substantially higher than ground; the third and fourth transistors (M6, M7) are NPN; the fifth, sixth, and seventh transistors (M1, M2, M3) are PNP; and the first and second diodes (Q1, Q2) are PNP.

[c8] 8. The bandgap reference circuit of claim 1 wherein the second bandgap reference unit comprises:
a second operational amplifier (114) having positive and negative input ends and an output end;
an eighth transistor (M1) having a source connected to the second voltage, a drain connected to the positive input end, and a gate connected to the output end;
a ninth transistor (M2) having a source connected to the second voltage, a drain connected to the negative input end, and a gate connected to the output end;
a fourth resistor (R1) connected between the first voltage and the positive input end;
a fifth resistor (R2) connected between the first voltage and the negative input end;
a third diode (Q1) having a collector and base connected to the first voltage, and an emitter connected to the positive input end through a sixth resistor (R3);
a fourth diode (Q2) having a collector and base connected to the first voltage, and an emitter connected to the positive input end; and
a tenth transistor (M3) having a source connected to the second voltage, a gate connected to the output end, and a drain connected to the second node (n2).

[c9] 9. The bandgap reference circuit of claim 8 wherein the second voltage is ground and the first voltage is sub-

stantially higher than ground; the first and second transistors (M4, M5) are PNP; the eighth, ninth, and tenth transistors (M1, M2, M3) are NPN; and the second and third diodes (Q1, Q2) are NPN.

[c10] 10. The bandgap reference circuit of claim 1 wherein the first bandgap reference unit comprises:
a first operational amplifier (112) having positive and negative input ends and an output end;
a fifth transistor (M1) having a source connected to the first voltage, a drain connected to the positive input end through a seventh resistor (R1a), and a gate connected to the output end;
a sixth transistor (M2) having a source connected to the first voltage, a drain connected to the negative input end through an eighth resistor (R2a), and a gate connected to the output end;
a ninth resistor (R1b) connected between the second voltage and the positive input end;
a tenth resistor (R2b) connected between the second voltage and the negative input end;
a first diode (Q1) having a collector and base connected to the second voltage, and an emitter connected to the drain of the fifth transistor (M1) through a third resistor (R3);
a second diode (Q2) having a collector and base con-

nected to the second voltage, and an emitter connected to the drain of the sixth transistor (M2); and
a seventh transistor (M3) having a source connected to the first voltage, a gate connected to the output end, and a drain connected to the first node (n1).

[c11] 11. The bandgap reference circuit of claim 10 wherein the second voltage is ground and the first voltage is substantially higher than ground; the third and fourth transistors (M6, M7) are NPN; the fifth, sixth, and seventh transistors (M1, M2, M3) are PNP; and the first and second diodes (Q1, Q2) are PNP.

[c12] 12. The bandgap reference circuit of claim 1 wherein the second bandgap reference unit comprises:
a second operational amplifier (114) having positive and negative input ends and an output end;
an eighth transistor (M1) having a source connected to the second voltage, a drain connected to the positive input end through an eleventh resistor (R1a), and a gate connected to the output end;
a ninth transistor (M2) having a source connected to the second voltage, a drain connected to the negative input end through a twelfth resistor (R2a), and a gate connected to the output end;
a thirteenth resistor (R1b) connected between the first voltage and the positive input end;

a fourteenth resistor (R2b) connected between the first voltage and the negative input end;
a third diode (Q1) having a collector and base connected to the first voltage, and an emitter connected to the drain of the eighth transistor (M1) through a sixth resistor (R3);
a fourth diode (Q2) having a collector and base connected to the first voltage, and an emitter connected to the drain of the ninth transistor (M2); and
a tenth transistor (M3) having a source connected to the second voltage, a gate connected to the output end, and a drain connected to the second node (n2).

[c13] 13. The bandgap reference circuit of claim 12 wherein the second voltage is ground and the first voltage is substantially higher than ground; the first and second transistors (M4, M5) are PNP; the eighth, ninth, and tenth transistors (M1, M2, M3) are NPN; and the second and third diodes (Q1, Q2) are NPN.

[c14] 14. A bandgap reference circuit comprising:
a CMOS p-channel circuit for providing a first reference voltage to a first node (n1);
a CMOS n-channel circuit for providing a second reference voltage to a second node (n2); and
a subtractor comprising:
a first transistor (M4) having a source connected to a

first voltage, and a drain and a gate both connected to the second node (n2);

a second transistor (M5) having a source connected to the first voltage, a drain connected to a third node (n3), and a gate connected to the gate of the first transistor (M4);

a third transistor (M6) having a source connected to a second voltage, and a drain and a gate both connected to the first node (n1);

a fourth transistor (M7) having a source connected to the second voltage, a drain connected to the third node (n3), and a gate connected to the gate of the third transistor (M6); and

an output resistor (RREF) connected between the third node (n3) and the second voltage.

[c15] 15. The bandgap reference circuit of claim 14 wherein the first and second transistors (M4, M5) are PNP, the third and fourth transistors (M6, M7) are NPN, the second voltage is ground, and the first voltage is substantially higher than ground.

[c16] 16. The bandgap reference circuit of claim 15 wherein the CMOS p-channel and n-channel circuits produce output reference voltages of under 1 volt at the first and second nodes (n1, n2) respectively.

[c17] 17. The bandgap reference circuit of claim 14 wherein the first voltage is approximately 0.9 volts relative to the second voltage being ground such that an output reference voltage at the third node (n3) is between 550 and 570 millivolts